The Neurological Impact of Perception of Architectural Space in Virtual Reality

Virtual Reality with Building Information Modelling and EEG

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The paper will present the preliminary findings from a pilot study that uses a virtual reality feedback collection methodology with building information modelling in combination with a neurological headset. All test subjects were fitted with both the Emotiv Insight and Oculus Rift Head Mounted Display and took a virtual tour through a 3D model. The matching of the test subjects' location in the model, field of view, the task, and the neurological activity, shows a possibility to link an architectural experience to specific emotional responses. This pilot study allows us to evaluate the methodology, frame and content in order to undertake a larger study using a more precise selection and delimitation. The results from this pilot study are hence focusing on addressing the framework for such a study to find out what sort of neurological data can be retrieved, and if the combination with virtual reality could be made useful. We find that there is a consistency in the data retrieved on the individual level. Even though the sample size in this pilot study does not allow concluding definite coherence, we find that the method, with modifications, could be useful to investigate the link between perception and architecture.

Keywords: *virtual reality, representation, perception, tradition, neurology*

INTRODUCTION

Through experiments with virtual reality, our research discusses the possibilities of representation models in architecture. We have performed a series of experiments using virtual reality in combination with other digital technologies such as 3d BIM modelling and eye tracking. We have been comparing how people experience architectural space using eye tracking technology in combination with qualitative questionnaires (Hermund et al. 2016, 2017, 2018). In our research, the next steps will be to combine our body of research with neurological feedback from the easy to use Emotiv Insight 5 channel EEG technology. Our research project is called VSR - virtual scenario responder [1], and we are currently working on a VR response system for the construction field that can be used in the design process, for modification and for validation of an architectural project, including user involvement. We want to connect the system to a wide range of different applications in new construction and restoration. There are many possibilities, and the required focus requires input from many different fields. An important part of the concept is a systematization of a question matrix and the subsequent studies of data. This matrix is created in collaboration between involved parties in construction and with psychologists focusing on cognitive processes, behavior and neurology.

We are currently working with an architectural case close to the city of Vejle in Denmark under the motto "Fitness for Everyone" which is a new section of the sports facility Gaarslevhallen, where accessibility is one of the important issues [2]. We use this case study to test how we can manage a VR workflow that will allow user feedback to be collected through our VSR system, without interfering unnecessary in the users' experience of the architectural atmosphere.

Previous research suggests that virtual reality can simulate a physical scenario to a degree where human behaviour shows correspondences, and is closer related to reality than for instance the experience of the space communicated through plan and section drawings, as traditionally used in architecture. If the technology is used correctly, a representation of architectural projects through virtual reality can significantly improve the usability of digital architectural building information models. (Hermund et al. 2018). Other pilot studies have been working with VR in combination with pupil dilation, as a means of capturing the behavioural aspect of perception (Moleta et al. 2018)

We believe that a virtual environment, through interacting with the environment in the model, can generate immersiveness (Steuer 1992), understood as the sensation of actually being present in an architectural space, even while one knows that this feeling is an illusion created by a digital model (Slater et al. 2009).

Our brains are combining input from different areas to create an experience (Mallgrave 2010). This does not inevitably means that we need photorealistic models to imagine an architectural space. The difficulty is to find a level of detail in the 3D model sufficient to convey the feeling of immersion - the sense of being present in the architecture. In assessing where a digital virtual reality representation can deliver a realistic, but still imaginative model for an architectural vision, we believe that the feedback generated from studies with the neurology headsets, can assist in deciding what elements to include in the modelling methodology. A recent neurology study comparing learning in VR to conventional media (flat 2D screen computers systems) shows that VR increases both sense of immersion and the risk of creating an increase in processing demands on working memory, which can lead to a decrease in knowledge acquisition. (Makransky et al. 2019). While the immersion is fundamental in the field of architecture, the cognitive overload should of course be avoided. This is also part of the reason to why we insist on removing unnecessary details from our test model, in order to reduce background noise.

EXPERIMENT SETUP

The pilot study consists of hardware, software, and methodology enabling a preliminary study of how to apply equipment and what methods to use.

Equipment and model

In this preliminary study, the test subjects were equipped with an Emotiv Insight 5 channel EEG technology brainwave recorder and an Oculus Rift HMD. The case study used is a digital 3D model of the architectural extension to the sports facility Gaarslevhallen, near the city of Vejle in Denmark, presented in 1:1 scale in VR. The test model has been modelled in Autodesk Revit as a sketch 3D digital model with minimum use of textures in order to eliminate as much background noise as possible.

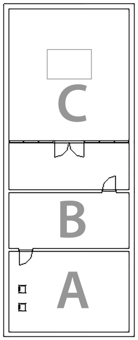


Figure 1
The tutorial room with start point is location A where the test subject can move around and watch some chairs. There are doors between the sections. Section is C where a scale model of the test case building is on display and from where the test subjects are teleported to begin the test.

Method
Test subjects whom did not respond with sufficient electric signal to the brain scanner were screened out before the test. We had twelve test subjects, but further screening out three test subjects (one case of severe motion sickness, and two cases of previous knowledge of the system and the 3D model) left us with eight usable test subjects. Six test subjects were students of architecture and two were architects and educators. One test subject was female and the rest was male. The test subjects were presented with a short brief explaining the outline of the pilot study. Before the real test, we had designed a tutorial VR room where the test subjects could practice moving around and interact eg. with opening doors and using a laser pointer tool. At the beginning of the tutorial room we included the recording of the compulsory individual neurological baseline where the test subject relaxed for fifteen seconds with open eyes and fifteen seconds with closed eyes. (Figure 1).

When the test subjects felt reasonably comfortable with the VR controls, going through the tutorial, they could point at a scale model of the case building, and were subsequently teleported to the start point of the 1:1 case building (location 1). Here they received a second brief, explaining where they should go in the model. In order to get a comparable data set, it was necessary to set up a location based task for the test subjects. There were four sequential locations that they should traverse: Outside the building (location 1), through the open foyer (location 2), to the changing room (location 3), to the fitness room (location 4), and finally back outside again (location 1). (Figure 2). The test subjects were told that they could interact with the "dummy people" in the model asking for directions, and real life staff from the research group would answer for the dummy people (Figure 3). The relatively free task was designed like this in order to simulate a possible close to normal use of the fitness facility without steering the test subjects more than necessary. Some guidance, however, seemed necessary in order to being able to analyse the data subsequently. Not every test subject follow the same route, but there are a significant overlap, that can be used to spot potential trends in the behaviour. We also wanted to have as much different data in the pilot study, simply to be able to select from a broader collection of potentially interesting trends.

Figure 3
The level of detail in the "dummy" people is kept at low poly to emphasize the sketchy model in an attempt to avoid distracting the test subjects.

Performance metrics diagrams
In order to collect data from the study, we screencaptured the live feed from the test subjects experience in VR while simultaneously capturing the feed from the Insight brain scanner (Figure 4). The full metrics diagrams were subsequently marked with the same entry points from A to I, to be used in the analysis. The markings are: A - starting point (location 1), B - entering the open foyer (location 2), C - entering the narrow hallway, D - entering changing room (location 3), E - leaving changing room, F - reentering foyer, G - Enter fitness room (location 4), H - leaving fitness,

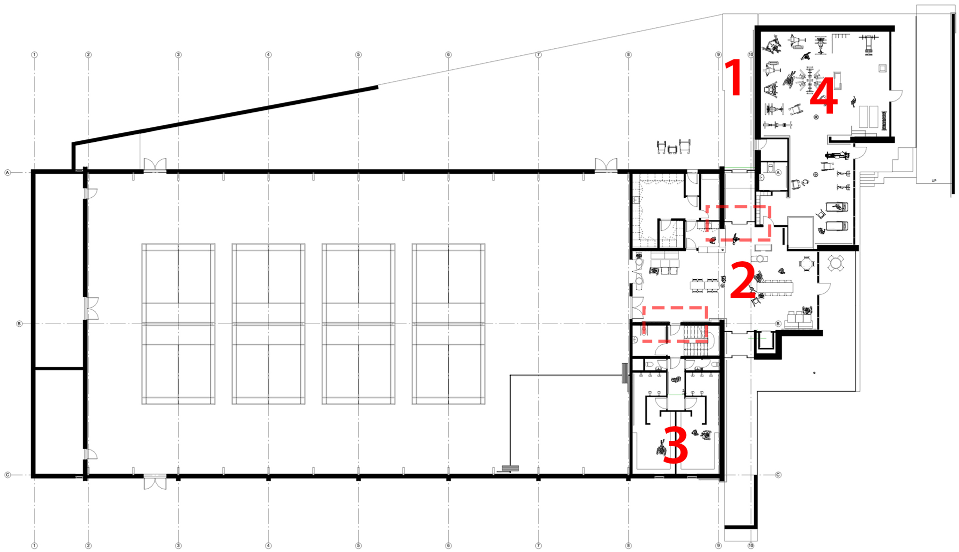


Figure 2
The sports facility Gaarslevhallen with the entry point (1), the foyer (2), the changing room (3), and the fitness room (4).

I - leaving foyer to go outside again (location 1) (see also Figure XX in the analysis chapter).

THE EMOTIV INSIGHT READINGS

The output from the Emotiv Insight is from the EEG signal transformed into graphs providing metrics showing six different areas. Since we are architects and not EEG analysts, it makes more sense in this context to use this output. Analysis of the raw EEG data is outside the scope for this study, but could be applied for future research, if undertaken be neuroscientists. We have chosen to focus more on Excitement, Interest and Engagement. These are relatively precise when measured with the Insight. A precision of about 70% for Interest to over 85% for Excitement, and Engagement a little less, when measured against standardised tests and other biosignals in Emotive's lab [3].

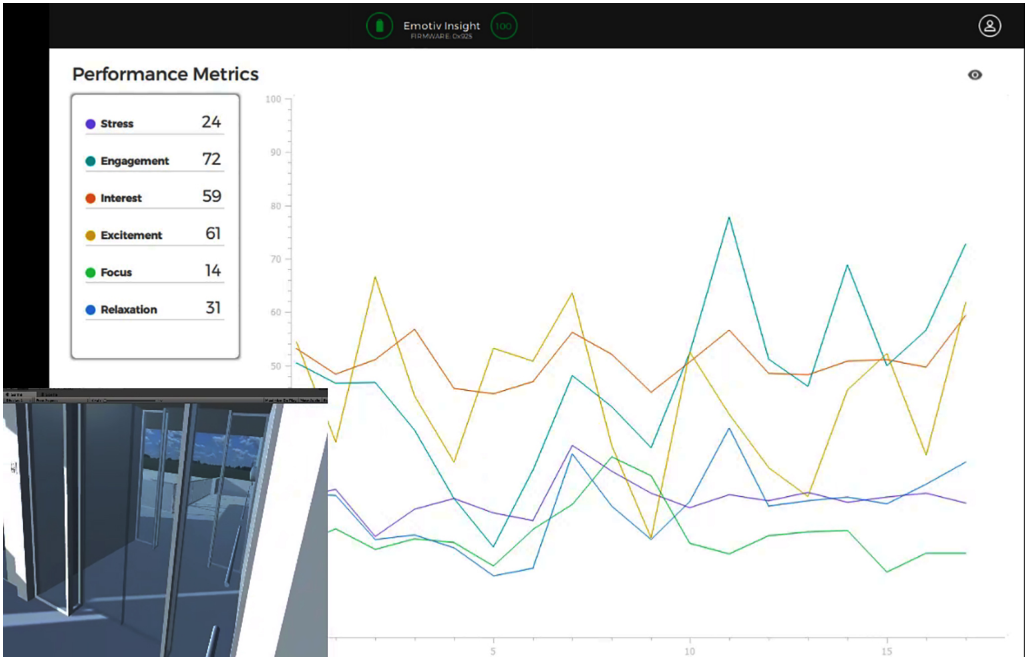
Emotiv labs describe these three performance metrics as follows:

Excitement (EXC) is an awareness or feeling of physiological arousal with a positive value. It is characterized by activation in the sympathetic nervous system, which results in a range of physiological responses including pupil dilation, eye widening, sweat gland stimulation, heart rate and muscle tension increases, blood diversion, and digestive inhibition. In general, the greater the increase in physiological arousal the greater the output score for the detection. The Excitement detection is tuned to provide output scores that reflect short-term changes in excitement over time periods as short as several seconds.

Interest (VAL) is the degree of attraction or aversion to the current stimuli, environment or activity and is commonly referred to as Valence. Low interest scores indicate a strong aversion to the task, high interest indicates a strong affinity with the task while mid-range scores indicate you neither like nor dislike the activity.

Engagement (ENG) is experienced as alertness

Figure 4
The screen capture with live feed from the test subjects experience in VR and simultaneously showing the feed from the Insight brain scanner.



and the conscious direction of attention towards task-relevant stimuli. It measures the level of immersion in the moment and is a mixture of attention and concentration and contrasts with boredom. Engagement is characterized by increased physiological arousal and beta waves along with attenuated alpha waves. The greater the attention, focus and workload, the greater the output score reported by the detection [4].

The Emotiv Insight also uses the EEG signals to measure Stress, Focus, and Relaxation. While we have kept these graphs on the performance metrics sheets (Performance metrics for pilot study [5]) we decided to focus our analysis on the above mentioned more precise criteria for reasons of clarity and simplicity in this pilot study.

POTENTIAL SOURCES OF ERROR

Several circumstances, both technical and physiological, proved to inflict the quality of the outcome of this study. The technical issues were mostly related to interference between the two independent system worn on the head and face, namely the signal from the Insight's electrodes on the scalp and the wireless connections from the leds of the Oculus Rift HMD. We tried both to cover the Insight with tin foil (Figure 5) and covering the LEDs of the HMD (Figure 6) but eventually found those countermeasures were insignificant in comparison to moving the wireless receiver of the Insight within close range (<2m) of the device. A more material factor that also influence the use of the Insight brain scanner is the amount and type of hair on the head of the test subjects. A very dense type of hair proved more difficult to facilitate the electric signal to the electrodes. This being said, we did also encounter some test subjects with very short hair and no connection, or almost no connection, to the brain scanner. Evidently, these test subjects cannot be used in the study. We had one case of motion sickness in relation to the HMD VR experience, which concluded the test before usable data could be collected.

Figure 5
Attempt to shield the brain scanner from electrical interference with a tin foil cap.

Figure 6
Shielding the LEDs on the VR HMD proved insignificant result in comparison to shortening to distance between the brainscanner's wireless transmitter and receiver.

The door sign symbols of the changing rooms had been confused due to updates of the 3D models. That meant that all male test subjects encountered two female dummy characters in the male changing room (Figure 7) and the female test subject was met by a male dummy in a wheelchair. This conceivably caused a nonintentional impact on that particular part of the test.

While the number of test subjects is not sufficient to provide a meaningful quantitative data set, we will focus on a qualitative analysis of the consistency of individual test subjects, and must constrain ourselves to some very cautious general considerations until more samples from more test subjects have been gathered in a larger study.

ANALYSIS

A first glance at the metrics of the eight test subjects does not reveal a very generous amount of neurological correspondence between them. This perhaps indicates that the results of the experiences of the architecture are very dependent on the individual, or that they are different in nature. We are well aware that the sample size consisting of eight test subject cannot be used as a quantitative data set. We will in the analysis focus on the consistency in the individual cases and successively only very cautious, and with many reservations, convey our assumptions of a preliminary comparative analysis. As a delimitation, we will focus on the metrics for Excitement, Interest and Engagement.

The test subjects are numbered (2, 3, 4, 6, 7, 9, 10) due the screen outs of the missing numbers.

In the following sample analysis, the capital letter corresponds to the markings on the metric diagrams mentioned in the experiment setup. Find higher resolution metrics diagrams online (Performance metrics for pilot study [5]).

Test Subject 2

An analysis of test subject 2 (Figure 8) show a general high Interest throughout the test. The Interest rise from the beginning (A) when receiving the instructions and remain high until the subject reaches a dead end in the basement (between E and F) and the

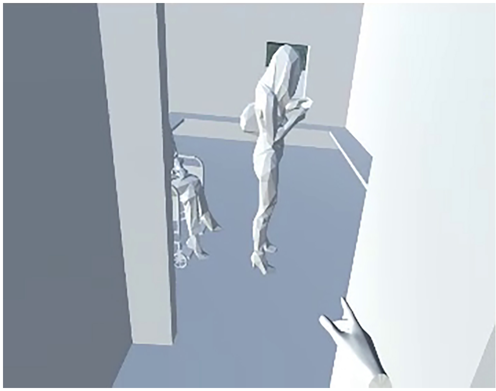


Figure 7
Female characters in the male changing room provided some measurable neuro feedback from some of the test subjects.

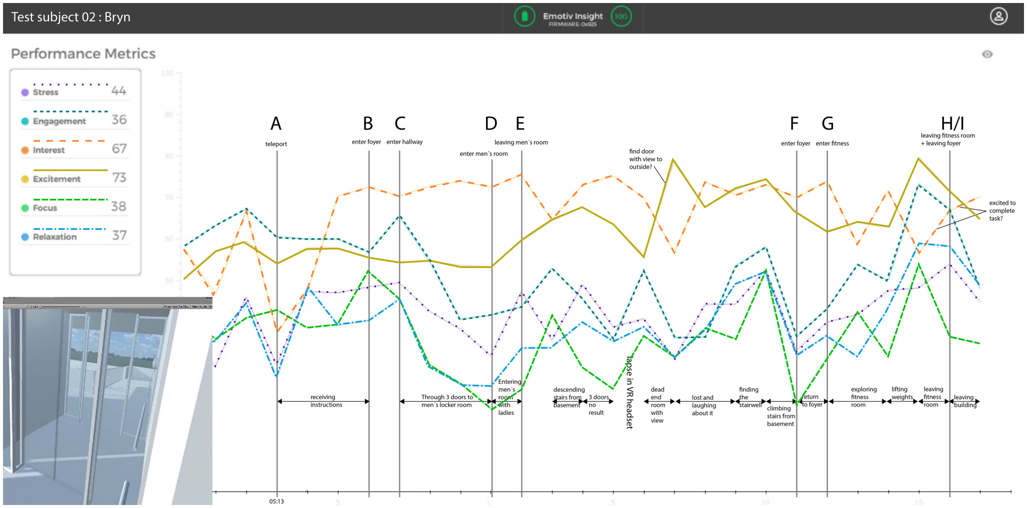


Figure 8
Performance metrics for test subject 2 showing graphs with markings corresponding to specific entry- and exit-points for all the test subjects.

Interest drops. At the same time though, the Excitement rises drastically when the subject finds a window from the dead end to the outside.

Towards the end of the test (between G and H), there is a similar rise in both Engagement and Excitement with a drop in Interest, when the subject engage in lifting weights in the fitness room. High readings of Engagement corresponds fine to the interactivity of opening doors (C), using stairs for the first time (E), getting lost and finding back again (E) and, in this case, trying to lift weights (G).

Test subject 3

The most striking reading is observed on the Excitement graph that has a some rather distinguishable fluctuations. When the test subject enters the foyer and begin to look around (B) the Excitement rises very high (from around 15 % to 65 %). This is at the time where the test subject discovers the right door and thus where to go next. When the test subject enters the narrow hallway (C), the Excitement lowers again. When entering the changing room (D) the Excitement rises gradually until the test subject re-enters the foyer (F). In the foyer itself, the Excitement rises again and peaks again when exploring he fitness room (G) and when concluding the test (I). This indicates a test subject who are excited to explore on his own, but also a possible link to the architectural perception of the space. The large foyer with lots of light and spacious qualities seems more exciting than the narrow hallway with only doors. Engagement also corresponds to the activity of opening doors, though on moderate scale. Interest remains mid-range and very steady throughout the test.

Test subject 4

In this test, the test subject seems to be very engaged with Engagement readings from 70-90% through most of the test. The Interest is mid-range and steady. The Excitement graph is not very high but peaking at the beginning while looking around and receiving the brief (A) and again in the changing room and when leaving this (D-E). The final peak is when the test is over (I). It is interesting that the Engagement graph seems to mirror the Excitement graph. When the Excitement rise, the Engagement drops. The highest peak of the Excitement is when the test subject momentarily gets lost in the shower. This test subject was very fast, almost as if playing a game that she needed to win. This could explain the very high level of engagement.

Test subject 5

While many fluctuations can be seen in this metrics graph, the Interest graph is the most stable (around 45-60%) through the test. A high level of Engagement and Excitement while receiving the brief (A) drops upon entering the foyer (B). Excitement rises again in the foyer, and Engagement peaks when finding and opening the door the narrow hallway (C). In the hallway they both drops. Opening the first set of doors corresponds to a rise in Engagement (C). The Excitement rises inside the changing room (D) until re-entering the foyer (F). In the foyer (between F and G) it peaks while the test subject is exploring and searching for the direction.

Test subject 6

Another example of a relatively high Engagement level, with two significant drops, throughout the test. While Interest is quite stable mid-range all the way, Excitement is low and peaks three times through the test. First peak is upon entering the foyer (B) and the next is in the changing room and leaving this (D, E, F), and the last is upon entering the fitness room (G). Again (as with test subject 4) we can observe a certain mirror effect between Engagement and Excitement, almost as if the mutually excluded on another. The two most radical drops of Engagement are when encountering a locked door (between C and D) and when turning all around confused about the way (between F and G). Both these drops of Engagement are synchronic with a slight rise both Excitement, but also Interest. A locked door seems slightly more interesting than the rest.

Test subject 7

The Interest graph is very stable at mid-range throughout the test. The Excitement graph peaks above mid-range twice in the test. The first peak appears at the beginning when the test subject is looking around and receiving the brief (between A and B) and the second time is in the narrow hallway just before entering the changing room (before D). We also observe a slight rise in excitement while exploring the fitness room (between G and H). A mirror effect between Engagement and Excitement can be traced almost consistently through the test.

Test subject 9

Again, we observe a stable mid-range Interest graph, slightly rising through the test. This test subject has a above mid-range Excitement graph around 65% in average. The Excitement graph is peaking while exploring (between A, B and C), entering doors (C, D, E, F), and when this test subject (male) purposefully entered the women's changing room, finding a dummy male in a wheelchair (due to the mistakenly replaced signage on the doors). In this case we do not observe a definitive mirroring between Engagement and Excitement as they on some occasions seem aligned instead of mirrored. Towards the end of the test there is a traceable, but not strong, mirror effect.

Test subject 10

In general, this test subject's metrics graphs are fluctuating with low drops and high rises on both sides of the mid-range for Engagement and Excitement. The Interest graph is relatively stable, fluctuating slightly below the mid-range. After receiving the brief (A) and beginning to explore on his own, the Excitement graph rises from low to above mid-range. It drops sharply around entering the foyer (B) and then rises (from B to C) to a high peak when entering the changing room (D). The Excitement detection remains above midrange for the rest of the test, dropping slightly when Engagement rises when re-entering foyer (F) and entering fitness room (G). A high peak of Excitement occurs (between F and G) when the test subject on his own accord explores the main sports arena, which is not specifically part of the test. At the exact same period a mirror effect on the Engagement can be observed. At the time the test subject enter the hallway (C), it seems like the Excitement and Engagement are shifting phases like a mirroring effect.

Preliminary comparison

As explained in the analysis introduction, a full comparison of the neurological feedback from the different test subjects makes little sense in this pilot study, when the data are from such a relatively scarce sample size. What is observed in this chapter is therefore mainly assumptions of potential correlations, which can only be qualified in a larger study.

One thing that seems to be correlating in this study, is that the Interest graph remains the most stable for all test subjects. It is also placed in the mid-range area for all test subjects, which indicate that they neither like nor dislike the activity. Another observation is the mirror effect of the Engagement and Excitement in some of the test subject metrics. This is not consistent, but an analysis on a larger sample size could probably be worthwhile in order to see in which cases one can be said to exclude the other.

In relation to the spatial quality of the architecture and its different appearances, e.g. in respectively the large open foyer and the narrow hallway with doors and stairs, it seems too early to say anything conclusive. A cautious estimation of the eight test subjects, in relation to the overall excitement in these two different spaces indicates that only three out of eight feels more excitement in the foyer than in the hallway. In six of the eight cases, we observe a rise in the Excitement when the test subjects enter the changing rooms. Likewise, we observe that six of the eight test subjects feel a drop in excitement once they exit (I) and the test is finished.

The exploration factor in relation to the Excitement is also something that could be a general tendency. When the test subjects are exploring freely, they tend to have a rise in the Excitement graph. This could be an entry point to investigate in a larger sample-size study. That there does not seem to be a clear pattern directly corresponding to the spatial qualities of moving through foyer and into the narrow hall, could simply indicate that the perception of architecture is a highly individual experience. Again, this cannot be investigated from this sample size. We will constrain ourselves to the observation that even though we can observe consistency within the individual test subjects performance metrics, no pattern can yet be discerned in relation to a general perception of the architectural qualities.

CONCLUSION

While we cannot conclude a precise terminology for the experience of architecture in a neurological perspective, we can conclude on the results of the methodology with the purpose of setting up a larger scale experiment with EEG and virtual reality in the field of architecture. The results from the neurological readings are no more or no less than what we expected from this preliminary study. It would have been intriguing if we could detect general correlations between the test subjects, but we did not expect that at this early stage. From the very broad nature of this study, we can extract and streamline the elements that proved to yield results in the individual cases.

The use of interaction, i.e. engaging in opening doors, shows engagement in the test subjects' behaviour. A virtual reality scenario incorporating such elements of interaction that cannot be provided to the same extent using traditional plan and section drawings or even non-immersive 2D and 3D, would be worthwhile to compare to more traditional architectural walkthrough animations in a neurological setting.

It is probably also necessary to focus a larger scale investigation on fewer architectural means. A more clear framework in the 3D model, e.g. limited to a transition from a small space to a larger space, from near darkness to a fully lit space, could perhaps be enough to gather data eliminating potential sources of error right from the beginning. In this case we will design a 3D model "in the lab" which will be more precise in the study than a real world 3D model.

From this preliminary study we can conclude that further studies with expertise from the field of architecture, neurology, and technology are required to generate more knowledge about the specific application of neurology in architectural perception. It seems to be a difficult but at the same time promising path towards a better understanding of the perception of architectural space that can eventually lead to a higher quality of architecture.

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